CHILE

ABSTRACT

The ICAP project was initiated in March 1999 and is lead by the National Environmental Commission (CONAMA) and P. Catholic University of Chile. The main goal of the project is to assist government officials and stakeholders to understand the air pollution benefits of energy technologies that reduce greenhouse gas emissions, and to build capacity to conduct co-benefits analysis of GHG mitigation measures on an ongoing basis. Ancillary benefits of GHG mitigation were assessed by comparing a Business As Usual (BAU) case to the current GHG abatement scenario being considered by CONAMA, a Mitigation scenario (CP) consisting of no-regrets measures that only target GHG abatement. A more in-depth, secondary analysis assessed the air pollution and GHG mitigation effectiveness of specific mitigation measures. The estimation of the public health benefits of both specific mitigation measures and the mitigation scenario was conducted based on the 'damage function approach', which models quantitatively each step in the causal chain of physical impacts and their economic valuation. The emphasis of the analysis is concentrated on the Metropolitan Region of Santiago and fine particulate matter ($PM_{2.5}$). Air quality and pollutant exposure to PM_{10}, $PM_{2.5}$ and coarse fractions was modeled using two methods, a Eulerian Box model approach and a source apportionment approach. Health effects studied included a range of mortality and morbidity endpoints; concentration-response functions were derived from relationships in both Chile and the USA. Domestic and international willingness-to-pay functions are used to develop estimates for the monetary value of the anticipated health effects. Results are obtained for Santiago and extrapolated to the national level. Estimates of the total potential for avoided health effects between 2000 and 2020 include thousands of deaths, hundreds of thousands of hospital and emergency room visits, and millions of disability days. Corresponding estimates of the potential benefit value of these avoided health effects in 2020 are between US$0.24 - 1.9 billion/yr or US$60-480/ton C-eq reduced. The analysis was presented to policymakers in Chile who noted its usefulness in allowing consideration of complex factors in coordinating different goals and for potentially directing international resources toward project involving harmonized policies and measures such as those that may be considered under the Clean Development Mechanism.

INTRODUCTION

Goals and Rationale

The main goal of the project was to assist government officials and stakeholders to understand the air pollution benefits of energy technologies that reduce greenhouse gas emissions, and to build capacity to conduct co-benefits analysis of GHG mitigation measures on an ongoing basis.

The specific objectives of this work effort include:

- Estimate the potential co-benefits associated with GHG mitigation scenarios currently being considered by local policy-makers
- Assess and quantify the air pollution benefits of specific mitigating measures for abatement of both GHG and local air pollution.

To explore the potential for such integrated strategies, the Chile ICAP team performed two distinct analyses: 1) an estimate of the ancillary benefits of a GHG mitigation scenario; and 2) an assessment of the air pollution and GHG mitigation effectiveness of specific mitigation measures.

Relationship to Other Studies

There have been no previous attempts in Chile to estimate the co-benefits of integrated policies. However, there are been previous studies in two areas that are requisite to this integrated analysis: the study of the mitigation potential for GHG from the energy sector, and the study of the social benefits from air pollution abatement policies. The current study builds upon both the results and the methods developed by these previous studies [1].

Project Team

The project was developed by a team of the School of Engineering of the P. Catholic University of Chile. The team was selected via a public bid managed locally by CONAMA. The head of the team is Luis Cifuentes, from the Industrial and Systems Eng. Dept. The members of the team include Hector Jorquera, from the Chemical Eng. Dept, and Enzo Sauma, Felipe Soto, Sandra Moreira, and Martin Guiloff, all from the Industrial and Systems Engineering Dept. The project team worked in close coordination with Juan Pedro Searle, from the National Environmental Commission (CONAMA).

Schedule of Key Activities

The ICAP project was initiated in Chile with an interagency and technical scoping meeting organized by CONAMA in March 1999. In August 1999, the ICAP-Chile team, lead by P. Catholic University initiated technical work. Preliminary results of the study have been presented in four different workshops. First, in November 1999 at the "Public Health Benefits of Improving Air Quality Through Cleaner Energy Use" Workshop, a side event at COP5 in Bonn, Germany, organized by the USEPA, NREL and WRI. Second in March 2000 at the "Expert Workshop On Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, Washington, DC., co-sponsored by IPCC, OECD, DOE, RFF , US EPA, WRI and the Climate Institute. The presentation on this latter workshop was included in the proceedings of the workshop edited by the OECD. In October, 2000, the results were presented in a Policy Makers' Meeting (described next), and also at a Mini-Course in conjunction with the Clean Air Initiative Workshop in Santiago. In November, 2000, the results will be presented at a side event at COP6 in The Hague.

METHODOLOGY

Overview – Description of the Analysis Conducted

To explore the potential for integrated strategies, the Chile ICAP team performed two distinct analyses, both using the same general method. First, ancillary benefits GHG mitigation were assessed by comparing a Business As Usual (BAU) case to the current GHG abatement scenario being considered by CONAMA, a Mitigation case (CP) consisting of no-regrets measures that only target GHG abatement. The comparison used a damage function approach, estimating the difference between Business as Usual and Mitigation in terms of emissions, ambient pollutant concentrations, health damages, and benefits. If such a comparison shows that mitigation measures selected for GHG abatement alone also have significant benefits to local air quality and human health, then this demonstrates that integrated strategies could be effective.

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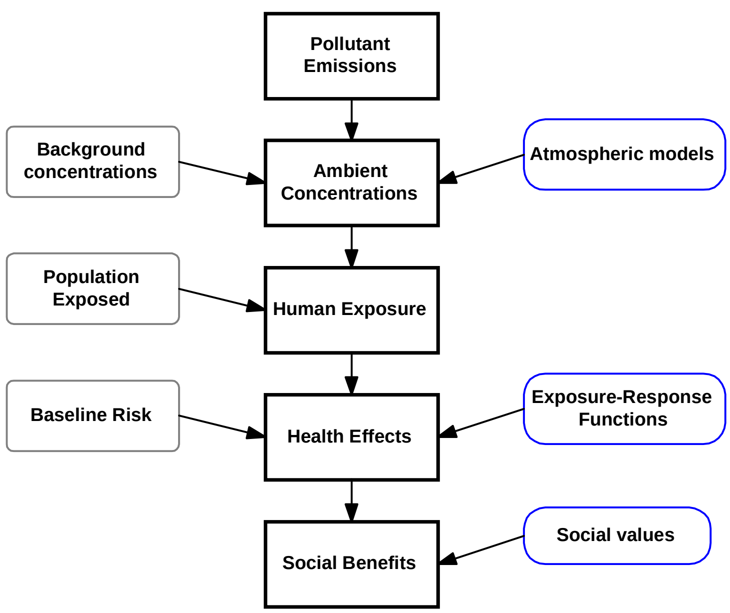
[1] These studies include: PRIEN. *Mitigación de Gases de Efecto Invernadero - Chile, 1994 - 2000*. Santiago: University of Chile, 1999., Cifuentes L. *Economic Valuation of the Social Benefits due to Health Effects. Study: Antecedentes para la Revisión de las Normas de Calidad de Aire contenidas en la Resolución N° 1215 del Ministerio de Salud, 1978*". Santiago,Chile: P. Universidad Católica de Chile, 1998., and Cifuentes LA. *Estudio de Seguimiento del Plan Piloto de Utilización de Combustibles Gaseosos en Buses de la Región Metropolitana. Volumen 2: Evaluación Económica*. Santiago: Departamento de Ingeniería Industrial y de Sistemas, P. Universidad Católica de Chile, 1999.

The second analysis assessed the air pollution and GHG mitigation effectiveness of specific mitigation measures. This analysis determined the cost effectiveness for both air pollution and GHG abatement of the selected mitigation measures, including fuel switching, electricity efficiency, and transportation sector measures. Using this analysis, possible criteria for evaluating the effectiveness of the measures in achieving both air pollution and GHG abatement were identified. This analytic method and approach to evaluation can guide the construction of an integrated air pollution and GHG mitigation scenario. Constructing such a scenario would be a logical next step following this study.

General Method

The estimation of the co-benefits of both specific mitigation measures and the mitigation scenario was conducted based on the 'damage function approach'. This method models quantitatively each step of the physical impacts and economic impacts, as shown schematically in the next figure.

Figure 1 Damage Function Framework used to Estimate the Social Benefits of a Reduction in Emissions of Primary Air Pollutants



The first step to estimate the social benefits is to link each policy or technological measure to the reduction in emissions pollutants. Once the changes in pollutant emissions have been assessed, it is necessary to link them to changes in ambient concentrations, population exposure, health effects and social benefits.

This method was applied at two different geographic and temporal dimensions. The first application was the aggregate analysis for the whole country, based on a previously developed mitigation scenario. The second application was the detailed analysis of some specific mitigation measures for the Metropolitan Region only.

Key Scoping Decisions

The scope of the project was defined jointly with NREL and CONAMA. The key scoping decisions are as follows:

- Only air pollution related health effects would be considered for the analysis of cobenefits.
- The emphasis of the analysis would be concentrated on the Metropolitan Region (Santiago and surroundings), given the data availability.
- Because that there were some previous studies concerning the energy sector, and that the project aimed at developing baseline and mitigation scenarios had not been designated yet, it was decided to base the analysis of the scenarios in a previous study contracted previously by CONAMA [2].
- Fine particulate matter ($PM_{2.5}$) was used as a sentinel pollutant, based on the availability of data and on local and international evidence that links it more consistently with health effects.
- The health effects selected for analysis were the same as previous studies developed for Santiago, which also included the economic valuation of health effects.

Air Pollution Dispersion Modeling to Estimate Air Pollutant Concentrations and Exposure Levels

This step is a crucial part of the method linking emissions of primary pollutants to social losses. For a detailed analysis, it should rely on atmospheric dispersion models, specifically on models that incorporate the complex set of chemical reactions occurring in the atmosphere. None of those models is available for Chile at this time. For this analysis, we estimated the impacts of emissions changes on PM concentrations based on two approximate methods, described in the following sections.

Method 1: Use of a Box Model to Develop Emission Concentration Relationships

A simplified methodology was used to estimate the future impacts of PM_{10}, $PM_{2.5}$ and coarse fractions. The starting point is the Eulerian Box model approach that describes mathematically the concentration of different air pollutants above a given area, accounting for emissions, chemical reactions, removal, advection of material in and out of the airshed and entrainment of material, assuming that the airshed is well mixed. This approach can be used to derive a linear relationship between emissions and concentrations, and it was used to generate long-term forecasts of CO and SO_2 for Santiago for 2000-2020. The emissions of CO and SO_2 come from fuel consumption, so the model parameters were calibrated using measured ambient concentrations and historical data on fuel consumption and fuel sulfur content, both on a monthly average basis. Data from 1990 through 1998 were used to derive these models, and seasonality was explicitly modeled to account for the poor ventilation conditions in fall and winter seasons in Santiago.

Next, in order to model the emission term for particulate matter fractions, it was assumed that the emissions of particulate matter can be expressed as a sum of contributions coming from mobile sources, stationary sources and other sources. The model was constructed based on the ratio of PM_{10}/CO in the emissions from the fleet in Santiago, the ratio of PM_{10}/SO_2 emissions in industrial and residential sources, and other PM_{10} emissions, like those coming from construction

[2] The baseline and a mitigation scenario had been developed previously in a study by the Research Program on Energy (PRIEN) from the University of Chile, in the study "*Mitigación de Gases de Efecto Invernadero - Chile, 1994 – 2000*"

and agricultural activities, wood burning, wind erosion, etc. The processes of dry and wet removal were accounted for in the mass balance equation coming from the box model formulation.

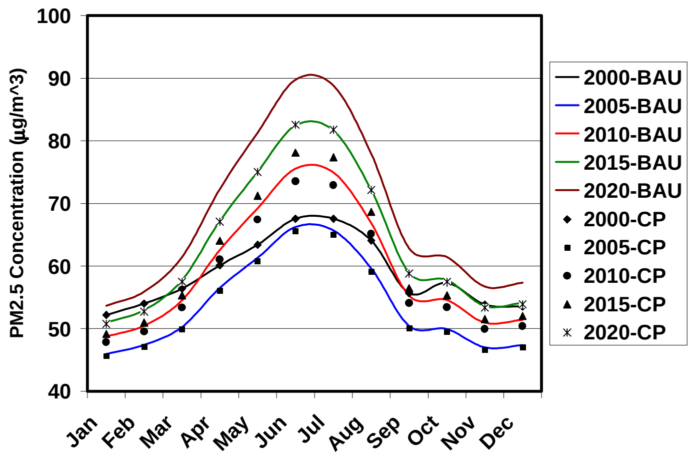
To validate this model, data gathered at Santiago for the fall and winter seasons from 1990 to 1994 were used to fit the model (in some cases, data from 1995 and 1996 were used to increase the database). The air quality data came from the MACAM monitoring network, and included hourly measurements of CO, SO_2, and surface wind speed plus daily measurements of PM_{10}, $PM_{2.5}$ and coarse fractions. In addition, daily precipitation records were collected to include wet deposition in the model fitting process. Using these data sets, it was possible to estimate the contribution to ambient concentrations of PM_{10}, $PM_{2.5}$ and coarse particles from mobile sources, stationary sources, and removal by dry and wet deposition. The contribution from secondary aerosols was not explicitly modeled, because of a lack of enough information in Santiago and because the chemistry and physics of these processes is far too complex to be included within a simplified model like this one. Nonetheless, the term accounting for this process was added in to the box model and appears as part of the coefficient associated with the reciprocal wind speed measured at the different monitor sites; of course, it cannot be distinguished from other contributions such as construction and agricultural activities, wind erosion, etc. that are all lumped within the same term in the linear model. We cannot estimate the magnitude of this uncertainty until a comprehensive simulation of those processes is carried out for Santiago. Nevertheless, the model parameters were fitted using actual data recorded at the monitoring network, so the model should represent reliably the PM levels within the city.

From these results, a working equation to estimate future concentrations under new emission scenarios was developed and applied to simulate impacts for the BAU and CP scenarios, using the following specific assumptions.

Background concentrations were kept at the same values as 1994. Although [Artaxo 1998] has estimated long range contributions from copper smelters that will undergo emission reduction plans, these plans will be pursued regardless of the long-term GHG policies (if any) in the country, that is, either under BAU or CP scenarios. In any case, these contributions are fairly small in a large urban area such as Santiago, whose air quality is dominated by local sources. The parameters obtained for the different monitor stations will be kept fixed at their estimated values for the calibration period (1990-1996).

The next figure shows the projected impacts of $PM_{2.5}$ at monitoring station B; similar results hold for the other stations, so they are not shown here. It is clear that by 2020 the two scenarios achieve different impacts, with CP concentrations being lower by up to 7 $\mu g/m^3$ per month, yielding annual average differences of about 4 to 5 $\mu g/m^3$.

Figure 2 Projections of $PM_{2.5}$ Concentrations at Monitoring Station B



Method 2: Source Apportionment of Fine Particular Matter Concentrations

In this approach, we estimated the changes in ambient PM concentrations due to changes in primary pollutant emissions using an alternative method. The method is based on source apportionment data on the relationship between $PM_{2.5}$ concentrations and primary pollutant emissions gathered in Santiago in 1996 and 1998[3]. We computed the fraction of $PM_{2.5}$ concentrations in Santiago attributable to each primary pollutant, based on those measurements, and obtained the fractions shown in the next table.

Table 1 Percentage of $PM_{2.5}$ Concentrations Attributable to Each Primary Pollutant in Santiago, 1998

Primary Pollutant	Percentage attributable	90% CI
Resuspended Dust	5.0%	(0.5% - 10%)
SO2	20.0%	(15.5% - 25%)
NMHC	0.0%	(0% - 0%)
NOx	30.0%	(21.1% - 39%)
PM10	33.5%	(24.6% - 42%)
Other	11.5%	

Source: own estimates based on [Artaxo 1996] , [Artaxo 1998]and [Artaxo, Oyola et al. 1999].

In the above table PM_{10} should be understood as primary emission of PM (mainly black carbon and organic carbon coming from combustion processes), whereas SO_2 and NO_x are associated attributable share of secondary sulphates and nitrates, respectively. Assuming that the

[3] Artaxo P. Aerosol Source Apportionment in Santiago de Chile Wintertime 1996: Applied Physics Department, Institute of Physics, University of São Paulo, 1996; Artaxo P. Aerosol Characterization Study in Santiago de Chile Wintertime 1998: Applied Physics Department, Institute of Physics, University of São Paulo, 1998; Artaxo P, Oyola P, Martinez R. Aerosol composition and source apportionment in Santiago de Chile. *Nucl. Inst. Meth. Phys. Res. B* 1999;**150:**409-416.

contribution of each primary pollutant remains fixed over time in the value given in Table 1 above, then the relative change in ambient $PM_{2.5}$ concentrations can be expressed as a function of the relative changes in the concentrations of the other pollutants.

This applies only to the fraction of the $PM_{2.5}$ concentrations above background concentrations. However, we should consider only the natural background, not the background due to emissions occurring elsewhere in the country. In effect, if we are conducting an analysis for the whole country, assuming a relatively uniform distribution of pollutant sources within the country, the background concentration in any given city will also change when the level of emissions changes within the whole country.

Health Effects Analysis

For the health effect analysis we used exposure-response functions obtained from the literature, mainly from the estimation of benefits of the Clean Air Act performed by EPA [EPA 1997] and from the recommendations of the World Health Organization by Ostro [Ostro 1996]. We complemented these sources with exposure response functions from studies performed in Santiago. For mortality we used our own results [Cifuentes, Lave et al. 2000]. For child medical visits, we used [Ostro, Eskeland et al. 1999]. All of the studies correspond to short-term effects, except for chronic bronchitis and long-term exposure mortality. In the same way as Ostro's recommendation [Ostro 1996], we used the coefficient for mortality due to long-term exposure from the study of Pope et al [Pope III, Thun et al. 1995] only for the high case, i.e., our mid estimate of mortality does not consider the chronic effects of pollution. Whenever possible, we used exposure-response functions based on $PM_{2.5}$. If they were available only for PM_{10}, we convert them to $PM_{2.5}$ using the relation $PM_{2.5} = 0.55\ PM_{10}$.

We considered three age groups in the analysis: Children 0-18 years, Adults, 18-64 years, and 65+ years, In some cases, we considered specific age groups, like asthma attacks, in which the exposure-response functions are for children below 15 years. The summary of the exposure-response coefficients for the effects considered is shown in the next table.

Table 2 Summary of Exposure-Response Coefficients Used in the Analysis

Endpoints	Age Group	β	σ_β	Source
Mortality (long term exp)	>30 yrs	0.00640	0.00151	Pope et al,1995
Chronic Bronchitis	> 30 yrs	0.02236	0.007891	Schwartz,1993
Mortality (short term exp.)	All	0.00120	0.000304	Cifuentes et al, 2000
Hospital Admissions RSP	> 65 yrs	0.00169	0.000447	Pooled
Hospital Admissions COPD	> 65 yrs	0.00257	0.000401	Pooled
Hosp. Adm Congestive heart failure	> 65 yrs	0.00135	0.000565	Schwartz & Morris, 1995
Hosp Adm Ischemic heart disease	> 65 yrs	0.00090	0.000400	Schwartz & Morris, 1995
Hospital Admissions Pneumonia	> 65 yrs	0.00134	0.000264	Pooled
Asthma Attacks	All	0.00144	0.000315	Ostro et al, 1991
Acute Bronchitis	8-12 yrs	0.00440	0.002160	Dockery et al., 1989
Child Medical Visits LRS	< 18 yrs	0.00083	0.000330	Ostro et al, 1999
Emergency Room Visits	All	0.00222	0.000427	Sunyer et al, 1993
Shortness of Breath (days)	< 18 yrs	0.00841	0.003630	Ostro et al, 1995
Work loss days (WLD)	18-65 yrs	0.00464	0.000352	Ostro et al, 1987
Restricted Act. Days (RAD)	18-65 yrs	0.00475	0.000288	Ostro et al, 1987
Minor Restricted Act. Days (MRAD)	18-65 yrs	0.00741	0.000704	Ostro et al, 1989

Economic Valuation

To estimate the social benefits associated to reduced health effects, it is necessary to estimate society's losses due to the occurrence of one extra effect. Several methods exist to value such losses. The most straightforward one is based on the direct losses to society stemming from the cost of treatment of each effect plus the productivity lost. This approach, known as the human capital method for mortality effects, and the cost of illness for morbidity effects, suffers from a serious limitation, by not considering the willingness to pay of the individuals to avoid the occurrence of an extra effect, or to reduce their risk of death. However, because values are easier to compute and defend, it has been used in previous analysis of quantification of air pollution effects, such as the economic valuation of the benefits associated to the Decontamination Plan of Santiago [Comisión Nacional del Medio Ambiente 1997].

We choose to use values that reflect the willingness to pay of individuals to reduce the occurrence of one extra effect. Since there are no such values available for Chile, the unit values of the effects are based on those used by the US EPA [EPA 1997], transferred to Chile using the ratio of the per capita income of both countries. By far, the more important effects are premature mortality. For these effects, we choose a lower bound from the range of values used by EPA, which became US$338 thousand after adjustment, for the year 1997. This value falls within the range of values that we have obtained in a pilot test of a contingent valuation study of willingness to pay for reducing mortality risks in Santiago [Cifuentes, Prieto et al. 2000]. The summary of values used in the analysis in shown in the next table. The values were updated annually using a constant growth in real per capita income of 2.6%.

Table 3 Unit Values for each Effect for the Year 1997 (1997US$ per effect)

Endpoint	mid	90% CI
Mortality (long term exp)	281,209	(111,956 - 707,906)
Chronic Bronchitis	45,556	(22,192 - 68,921)
Mortality (short term exp.)	338,549	(134,785 - 852,252)
Hospital Admissions RSP	2,796	(2,796 - 2,796)
Hospital Admissions COPD	3,624	(3,597 - 3,651)
Hosp. Adm Congestive heart failure	3,832	(3,815 - 3,849)
Hosp. Adm Ischemic heart disease	4,755	(4,742 - 4,767)
Hospital Admissions Pneumonia	3,670	(3,654 - 3,686)
Asthma Attacks	7	(3 - 11)
Acute Bronchitis	10	(4 - 16)
Emergency Room Visits	54	(33 - 74)
Child Medical Visits	165	(133 - 198)
Shortness of Breath (days)	1	(0 - 2)
Work loss days (WLDs)	18	(18 - 18)
RADs	9	(5 - 12)
MRADs	8	(5 - 12)

Source: Values from EPA (1999) transferred for Chile using the ratio of per capita income.

Application: Analysis of Current Mitigation Scenario

The general method above was first applied to the analysis of the current GHG mitigation scenario of CONAMA, which is based on no-regrets measures that were selected according to their GHG mitigation effectiveness. This application assesses the value of health effects associated with the air quality changes that occur because of the GHG mitigation.

Design of Baselines and Scenarios

Two emissions scenarios were considered: the Business-as-usual scenario (BAU), in which no GHG mitigation measures are taken, and a Climate Policy scenario (CP), in which measures are taken to reduce emissions of GHG.

We relied on the results obtained in a previous study contracted by the Chilean Environmental Commission to the Research Program on Energy of the University of Chile [PRIEN 1999]. The study projected the emissions for several greenhouse gases, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) and several primary pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NOx) and non-methane hydrocarbons (NMHCs). Those projections were based on an engineering, bottom-up approach, considering technological measures like efficiency improvements and fuel switching to obtain emissions reductions. For the base case, policies that are currently in place and those which are scheduled to be applied were considered. In particular, all the measures of the Decontamination Plan for the Metropolitan Region that are scheduled to be implemented in Santiago were considered [Comisión Nacional del Medio Ambiente 1997], as well as the future investments in infrastructure contained in the national strategic plan developed by the Ministry of Public Works [MOP 1997].

Application: Analysis of Specific Mitigation Measures

Following the analysis of the GHG mitigation scenario, the general method was then applied to an analysis of the mitigation measures. This application assesses the cost effectiveness of selected mitigation measures in reducing both $PM_{2.5}$ and GHG emissions simultaneously.
This involved evaluating the changes in emissions of both GHG and local pollutants for each measure, comparing the base case (i.e., the situation without applying the measure) and the situation in which the measure is implemented. With the information on the local pollutant emission reductions it was possible to compute the change in $PM_{2.5}$ concentrations. With the previously derived impact factors and valuation factors, we obtained the social benefit due to reduced health effects in the scenario with reduced HDP emissions. The costs of the implementation of the measures were computed. From the information of the costs and emissions reductions indicators of cost-effectiveness and net benefits were calculated. T he analysis was conducted for Santiago only.

The method involved (1) estimating the baseline and reduced emissions for all local pollutants (CO, SO_2, NO_x, PM, resuspended dust) using emission factors and activity levels for each measure; (2) estimating the social benefit as the marginal benefit of changes in $PM_{2.5}$ concentrations in Santiago due to the implementation of the abating measure using the linear relationships under the Box and Source Apportionment models; (3) estimating the difference in investment, operations and maintenance, and fuel costs necessary to implement the measure. All costs were assessed at social prices, following the directions of the Planning Ministry of Chile. Investments were annualized using a 12% real discount rate, the usual discount rate used in Chile for evaluation public investments.

The measures evaluated can belong to three types, and are described in the following sections.

Fuel Switching Measures

- ❖ Change of Residential wood and kerosene heaters to natural gas: we considered the conversion of 50% of all residential wood and kerosene used to home heating to natural gas
- ❖ Conversion of industrial boilers - from diesel to natural gas: we considered the conversion of 50% of all remaining diesel based industrial boilers to natural gas

These measures represent normal fuel switching in the residential and industrial sector. It should be noted that natural gas became available in the Metropolitan Region in 1997, and since then most of the fixed sources have switched to its use, however, some diesel-fired boilers remain in operation. We conducted the analysis for these units.

Energy Efficiency Measures

We considered three electricity savings measures:

- ❖ Change from incandescent to CFL lamps in the residential sector.
- ❖ Change from regular fluorescent lamps to fluorescent lamps with high efficiency reflectors in the residential sector
- ❖ Change from mercury to sodium lamps in public lighting

The level of penetration assumed for each measure was relatively modest. T here are two thermal power plants located in Santiago. An older, coal and diesel fired (Renca), and a newer, combined-cycle natural gas turbine power plant (Nueva Renca). The older plant operates only on peak hours, while the newer plant is a baseload plant that operates almost continuously. To compute the impact on emissions reductions due to the electricity savings measures it is necessary to model the whole electric sector, which has complex dispatching rules. As a simplifying assumption, we computed the impact for all the electricity efficiency measures assuming that the electricity savings would be realized in either one of the two plants.

Transport Sector Measures

The transport sector is one of the biggest emitters in Santiago. We considered five measures whose main aim is to reduce air pollutant emissions:

- ❖ Adoption of CNG buses instead of diesel buses for the normal renewal of the bus fleet
- ❖ Adoption of Hybrid diesel-electric buses instead of diesel buses for the normal renewal of the bus fleet.
- ❖ Conversion to CNG of existing diesel buses to operate on a mix of diesel and natural gas using an AFS conversion kit.
- ❖ Retrofit of older diesel buses with Diesel particulate traps.
- ❖ Forced taxi renovation of older (non catalyst equipped) taxicabs with new model-year vehicles.

The analysis for the CNG buses was based on a previous pilot study of the introduction of such buses in Santiago [Cifuentes 1999], where the reduction in local pollutants was estimated, based on tests conducted in the Motor Test Center in Sweden. Both new and conversion of CNG buses produces a reduction in GHG emissions (including CH_4 emissions). The retrofit of existing diesel buses with particulate traps is another pollution abatement measure currently being considered by the authority, but which has an increase in CO_2 emissions. The forced renovation of a portion of the taxi fleet also has both global and local emissions reductions. For the buses measures, we assumed a penetration of 500 buses, per measure. This is about two-thirds of the total number of new buses every year. For the forced taxi renovation, we also assumed a renovation of 500 vehicles. The level of the penetration of the measure does not impact the unit indicators, only the total reductions achieved by the measure.

Since oil costs have risen sharply during 2000, we assessed the costs of the transportation measures using two scenarios: for the low price scenario we used the average prices for the year 1999. The High Price scenario corresponds to the fuel prices observed in Santiago in September 2000.

ANALYTIC RESULTS

Analysis of a Feasible Mitigation Scenario

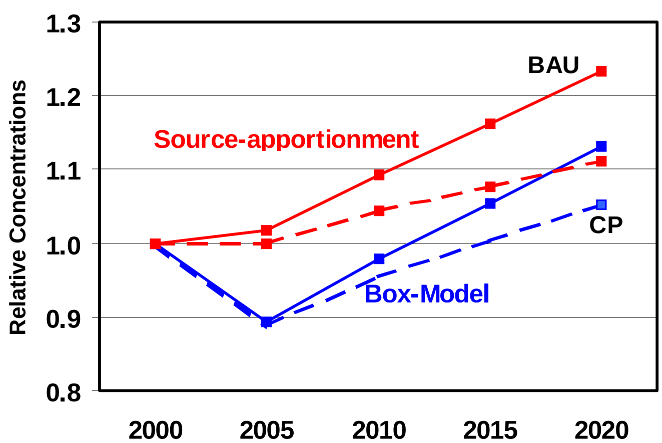
We first present the results of the GHG mitigation scenario analysis, comparing the BAU and CP cases. Table 4 compares the estimated carbon equivalent emissions for the BAU and CP scenarios. Modest assumptions regarding no-regrets energy efficiency and fuel substitution measures result in decreases of 1 and 4 million tons of carbon equivalent in 2010 and 2020 respectively.

Table 4: Projected Greenhouse Gas Emissions under Business As Usual (BAU) and Mitigation (CP) Cases
(million metric tons Carbon-equivalent emissions)

	2000	2010	2020
Business As Usual	16	23	29
Mitigation	16	21	25
Difference	0	1	4

We estimated the evolution of $PM_{2.5}$ concentrations in time. The next Figure shows the mid estimates of the projected $PM_{2.5}$ concentrations for each scenario, using both the Box Model and Source Apportionment methods of estimating the concentrations, with year 2000 as the point of reference.

Figure 3 $PM_{2.5}$ Concentrations Relative to Year 2000 Concentrations, for both Methods of Estimating the Concentrations



The figure shows that both methods produce similar results for each scenario, BAU and CP, with most of the $PM_{2.5}$ concentration increase driven by the increase in NO_x and PM emissions. The two methods result in different estimates of the difference between the BAU and CP, and different curve shapes, because of the two methods differ in how they weight the importance of emission changes of each primary pollutant.

Applying the changes in $PM_{2.5}$ concentrations to the exposed population in each city, it is possible to compute the excess health effects for each scenario. The next table shows the avoided excess health effects in the year 2010 and 2020. The excess effects have been computed assuming there is no threshold in any of the effects. The table shows the mid value of the effects for each policy scenario, grouped by type of effect, summed up over all age groups, and the 90% confidence interval. We show the results for the source apportionment method. The values for the Box model are smaller.

Table 4: Avoided Health Effects for the Years 2010 and 2020

Endpoint	2010 mid	2010 90% CI	2020 mid	2020 90% CI
Premature Deaths	100	(62 - 431)	305	(189 - 1,290)
Chronic Bronchitis	710	(503 - 854)	2,157	(1,526 - 2,572)
Hospital Admissions	619	(480 - 797)	1,887	(1,450 - 2,423)
Emergency Room Visits	9,972	(6,431 - 14,882)	30,095	(19,654 - 44,984)
Child Medical Visits	4,837	(1,919 - 8,178)	14,642	(5,866 - 24,878)
Asthma Attacks & Bronchitis	133,022	(86,530 - 183,840)	399,351	(263,016 - 556,863)
Restricted Activity Days	2,878,743	(1,868,859 - 3,716,428)	8,804,442	(5,660,315 - 11,270,793)

Note: $PM_{2.5}$ concentration changes estimated using source apportionment method, equation (6).

The next table shows the total number of effects avoided from 2000 to 2020 for the BAU-CP scenario comparison.

Table 5: Total Number of Health Effects Avoided in the CP Scenario with Respect to the BAU Scenario during the Period 2000 to 2020

Endpoint	Total effects avoided mid	Total effects avoided 90% CI
Premature Deaths	2,771	(1,546 - 10,840)
Chronic Bronchitis	18,130	(10,710 - 22,170)
Hospital Admissions	15,000	(12,930 - 20,760)
Emergency Room Visits	247,200	(166,600 - 353,400)
Child Medical Visits	118,600	(47,560 - 205,400)
Asthma Attacks & Bronchitis	3,339,000	(1,981,000 - 4,998,000)
Restricted Activity Days	75,430,000	(43,650,000 - 96,670,000)

Note: $PM_{2.5}$ concentration changes estimated using source apportionment method, equation (6).

For the whole period of analysis, the mid estimate is around 2,800 deaths that can be avoided, with a 90% confidence interval of 1,500 to 10,800 (the upper bound of this interval is high because it includes long-term exposure deaths). Most of these effects will occur in the Metropolitan Region of Santiago.

Using the unit values shown in the preceding section, we computed society's social losses due to these health effects. The difference of the damages for each scenario is the social benefit of the mitigation measures.

Table 6: Social Benefits for 2010 and 2020 (Millions of 1997US$)

Endpoint	2010 mid	2010 90% CI	2020 mid	2020 90% CI
Premature Deaths	53.0	(15.1 - 371.3)	210.6	(60.3 - 1,494.0)
Chronic Bronchitis	41.8	(26.8 - 67.3)	168.4	(106.8 - 265.8)
Hospital Admissions	3.2	(2.6 - 3.9)	12.8	(10.4 - 15.7)
Emergency Room Visits	0.7	(0.4 - 1.1)	2.9	(1.6 - 4.6)
Child Medical Visits	1.1	(0.5 - 2.0)	4.3	(1.9 - 7.9)
Asthma Attacks & Bronchitis	1.3	(0.5 - 2.4)	5.3	(2.2 - 9.5)
Restricted Activity Days	18.4	(14.4 - 23.9)	74.0	(56.4 - 94.9)
Total	**119.6**		**478.2**	

Note: $PM_{2.5}$ concentration changes estimated using source apportionment method.

All the previous results have been obtained using source apportionment model to estimate the change in $PM_{2.5}$ concentrations. Finally, another way to look at these results is to compute the average social benefit accrued from the reduction of each ton of carbon. This is obtained by simply dividing the benefits by the equivalent carbon reductions in each year.

Table 7: Average Social Benefit per ton of Carbon (1997US$/tonC)

Year	Atmospheric Model: Source appmt	Box Model	Avg of two models
2010	90 (42 - 337)	48 (21 - 190)	69 (21 - 337)
2020	129 (60 - 479)	79 (39 - 284)	104 (39 - 479)

Analysis of Mitigation Measures

In this section, we present the results of the analysis of the set of measures considered that simultaneously reduce conventional air pollution and GHG, and evaluate their effectiveness in simultaneously mitigating both. This analysis develops a method and approach for the evaluation, and also produces results that could be used to screen mitigation measures for an integrated strategy. The next table and figure show the summary reductions in emissions obtained by the application of each measure.

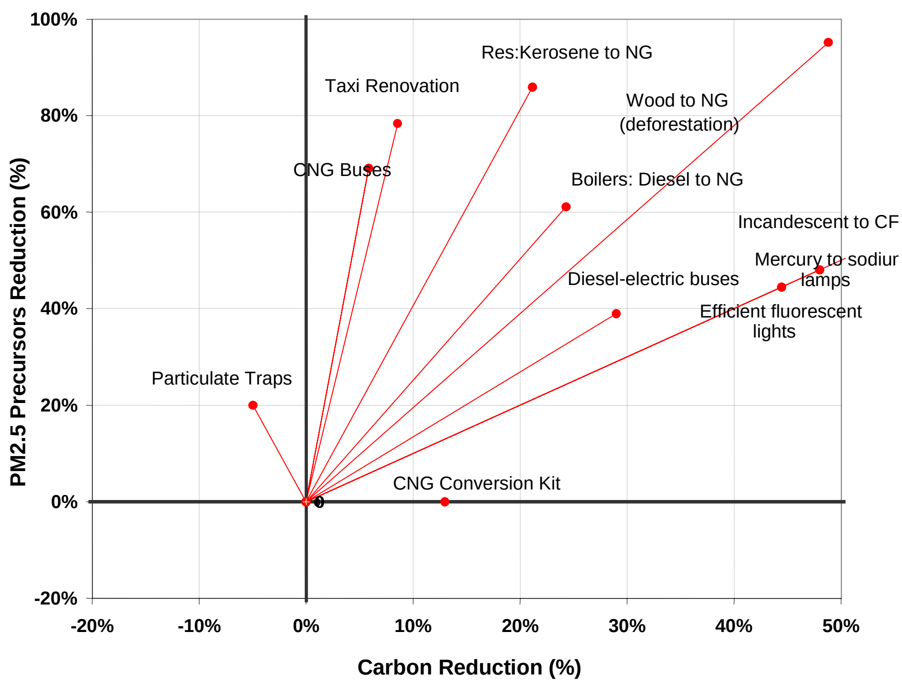
It should be noted that almost all measures have positive reductions for both pollutants, except particulate traps, which increase carbon emissions due to increased fuel consumption, and the conversion of diesel buses to CNG, which has no measurable effect on PM concentrations. Electricity savings measure, by reducing the generation of electricity, reduce all pollutants by the same percentage.

Table 8: Summary of Emission Reductions for Each Measure (%)

Measure	CO_2	CO	SO_2	NO_x	NMHC	PM	$PM_{2.5}$ (*)
Fuel Switching Measures							
Residential wood to NG		99.1%	-	88.9%	-	99.8%	95.1%
Residential Kerosene to NG	21%	7%	99.7%	11%	-	98%	85.9%
Boilers - Diesel to NG	24%	2%	99.8%	-9%	-	46%	61.1%
Electricity Savings Measures							
Incandescent to CFL	80%	80%	80%	80%	80%	80%	80%
Efficient reflectors for FL	44%	44%	44%	44%	44%	44%	44%
Sodium lamps for Public lightning	48%	48%	48%	48%	48%	48%	48%
Transportation Sector Measures							
CNG buses	6%	-73%	100%	73%	27%	96%	69.1%
Hybrid Diesel-Electric Buses	29%	76%	29%	40%	43%	64%	39.0%
CNG Conv. Kit	13%	-	-	-	-	-	-
Diesel particulate traps	-5%	80%	-2%	-	80%	85%	20%
Taxi renovation	8.5%	95%	-0.1%	82.6%	77.3%	65.5%	78.4%

Notes: *this refers to concentration changes estimated in Santiago due to the emission reductions in the precursors of $PM_{2.5}$

Figure 4 Carbon vs $PM_{2.5}$ Precursors Percentage Emission Reductions for each Mitigation Measure.



Cost-Effectiveness Analysis

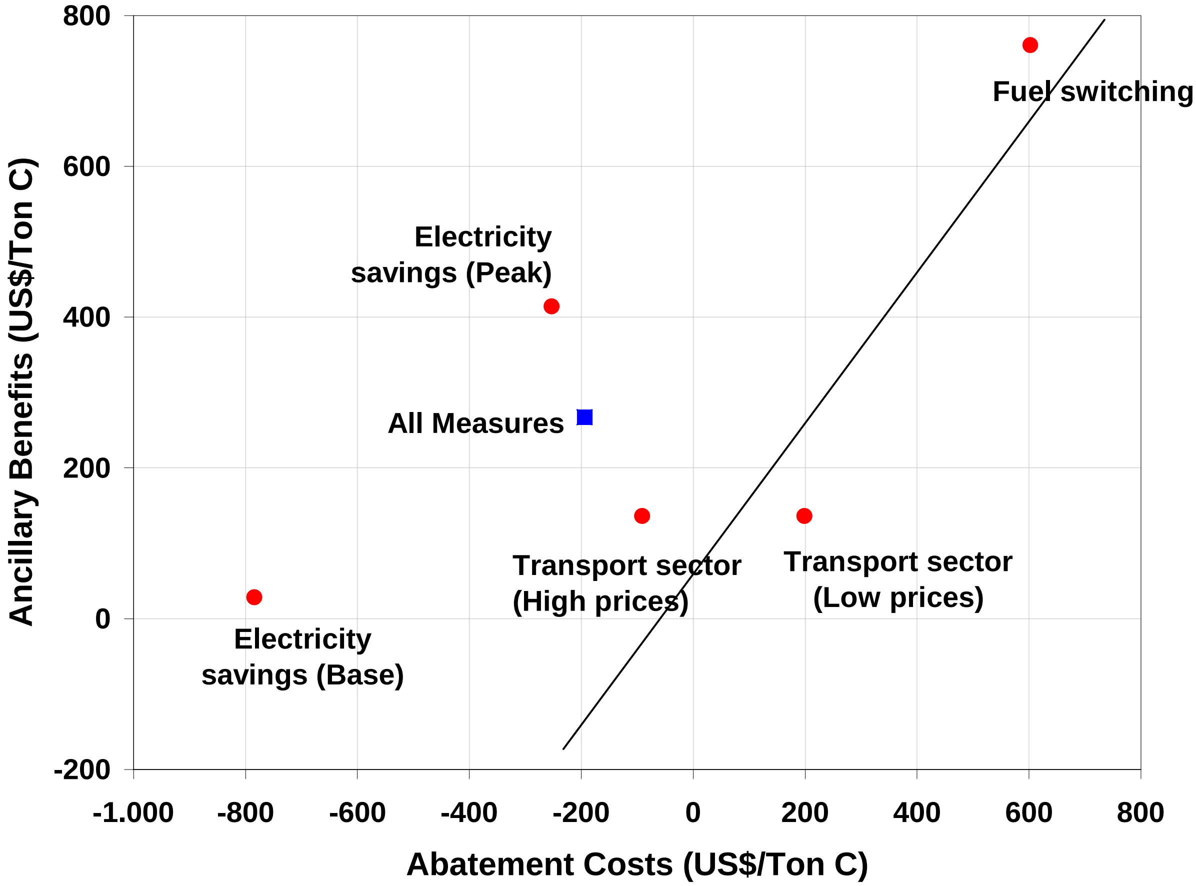
Based on the emission reductions for $PM_{2.5}$, it is possible to compute costs and ancillary benefits. The next table shows a summary of the costs and benefits of the measures that were analyzed.

Table 9: Summary of Cost and Benefits Indicators for Each Measure

Mitigation Measure	**Carbon Emissions Reductions**		**$PM_{2.5}$ Concentrations Reductions**		**Relation of $PM_{2.5}$ to C em. Reds.**	**Abatement Cost**	**Ancillary Benefits**	**Net abatement cost**
	Ton C	%	μg/m^3	%	(μg/m^3) /TgC	US$/tonC	US$/ton C	US$/ton C
Fuel Switching								
Residential Wood to NG	15,467	-	0.123	95%	-	148	-199	347
Residential wood to NG (deforestation)	14,824	49%	0.123	95%	4.3	-155	207	-362
Residential Kerosene to NG	12,104	21%	0.113	86%	2.3	1,300	233	1,067
Boilers - Diesel to NG	14,498	24%	0.103	61%	2.8	-465	177	-642
Electricity Savings								
Incandescent to CFL lamps (Peak hours)	67,610	80%	1.1	80%	16.6	-353.5	414	-768
Incandescent to CFL lamps (Normal hours)	21,779	80%	0.02	80%	1.1	-1097.3	28	-1,126
Efficient fluorescent reflectors (Peak hours)	9,323	44%	0.15	44%	16.6	-92.5	414	-507
Efficient fluorescent reflectors (Normal hours)	3,003	44%	0.003	44%	1.1	-287.2	28	-315
Sodium lamps (Peak hours)	24,583	48%	0.4	48%	16.6	-35.6	414	-450
Sodium lamps (Normal hours)	7,919	48%	0.01	48%	1.1	-110.5	28	-139
Transportation Sector								
CNG bus (2000 prices)	1,293	6%	0.171	70%	11.2	-315	3,304	-3,619
CNG bus (1999 prices)	1,293	6%	0.171	70%	11.2	3,243	3,304	-61
Hybrid Diesel-Electric Buses (2000 prices)	6,400	29%	0.097	39%	11.2	-110	376	-486
Hybrid Diesel-Electric Buses (1999 prices)	6,400	29%	0.097	39%	11.2	137	376	-239
CNG Conv. Kit (2000 prices)	1,805	13%	0	0%	25.3	-266	0	-266
CNG Conv. Kit (1999 prices)	1,805	13%	0	0%	25.3	779	0	779
Diesel particulate traps	-696	-5%	0.070	20%	25.3	-1,451	-2,520	1,069
Taxi renovation	197	9%	0.011	78%	5.8	-124	1,336	-1,460

An illustrative way to look at these results is to plot the abatement costs of carbon (in terms of dollars per ton of carbon equivalent abated) versus the ancillary benefits per ton of carbon abated (the ancillary benefits correspond to the monetized health benefits due to the reductions in $PM_{2.5}$ concentrations). The next figure shows the average abatement cost and ancillary benefits for each set of measures analyzed.

Figure 5 Sectoral Averages Abatement Cost and Ancillary Benefits

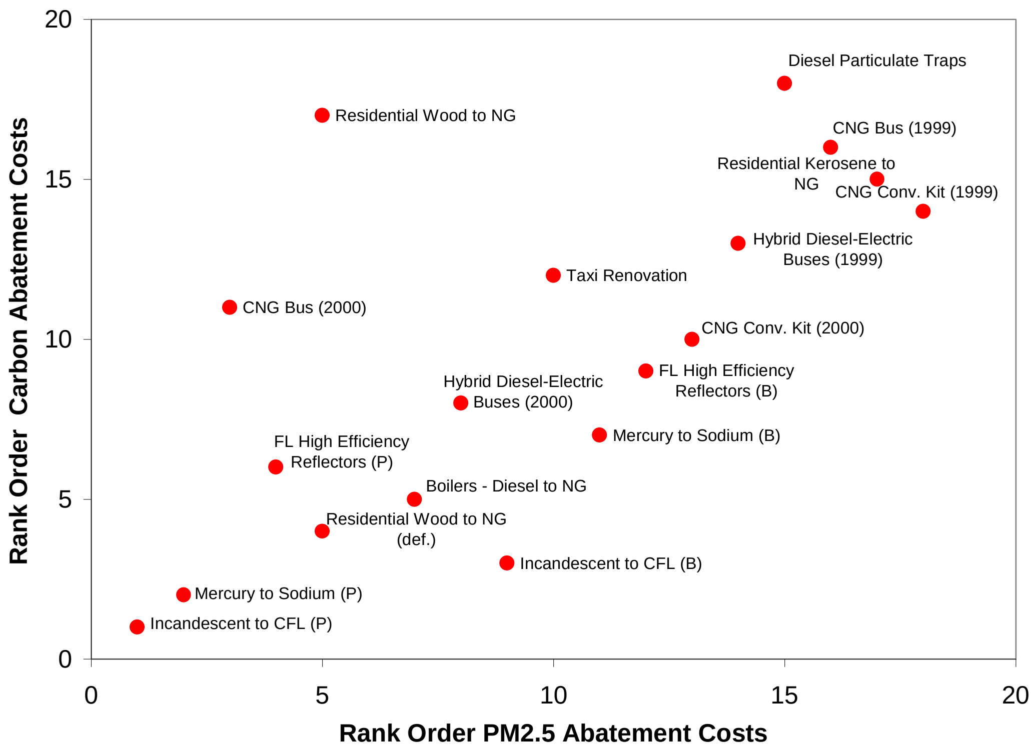


This figure shows that all sectors, except the transport sector for the low prices (prices similar to the ones observed in 1999) fall to the left of the 45° line, meaning that their net mitigation costs are negatives. Actually, most of the measures have a negative abatement cost, because they produce a net savings. Of course, this finding is the consequence of the 'engineering bottom up' approach to estimating the costs of the measures. No costs associated with behavioral changes, nor market imperfections, nor barriers to the implementation of the measures have been considered.

Ranking of Measures

An interesting exercise is to compare what the best measures are, according to their reductions of carbon or local pollutants. We ranked the measures according to their abatement cost, both for carbon and for $PM_{2.5}$ precursors, considering first the measures that produce reductions at negative cost, then those measures with positive costs, and finally the measures with negative reductions. The next figure shows the measures plotted according to their rank order in each criteria (rank orders defined as 1 to the best measure, 2 to the next one, and so on). Most of the measures have similar ranks for both pollutants, i.e., most of the measures are close to an imaginary 45° line in the graph. However, there are some notable exceptions, like the CNG buses and residential wood to NG, which have a much better ranking for $PM_{2.5}$ than for carbon reductions.

Figure 6 Comparison of the Ranking of Measures by their Carbon Abatement Costs and their $PM_{2.5}$ Precursors Abatement Costs

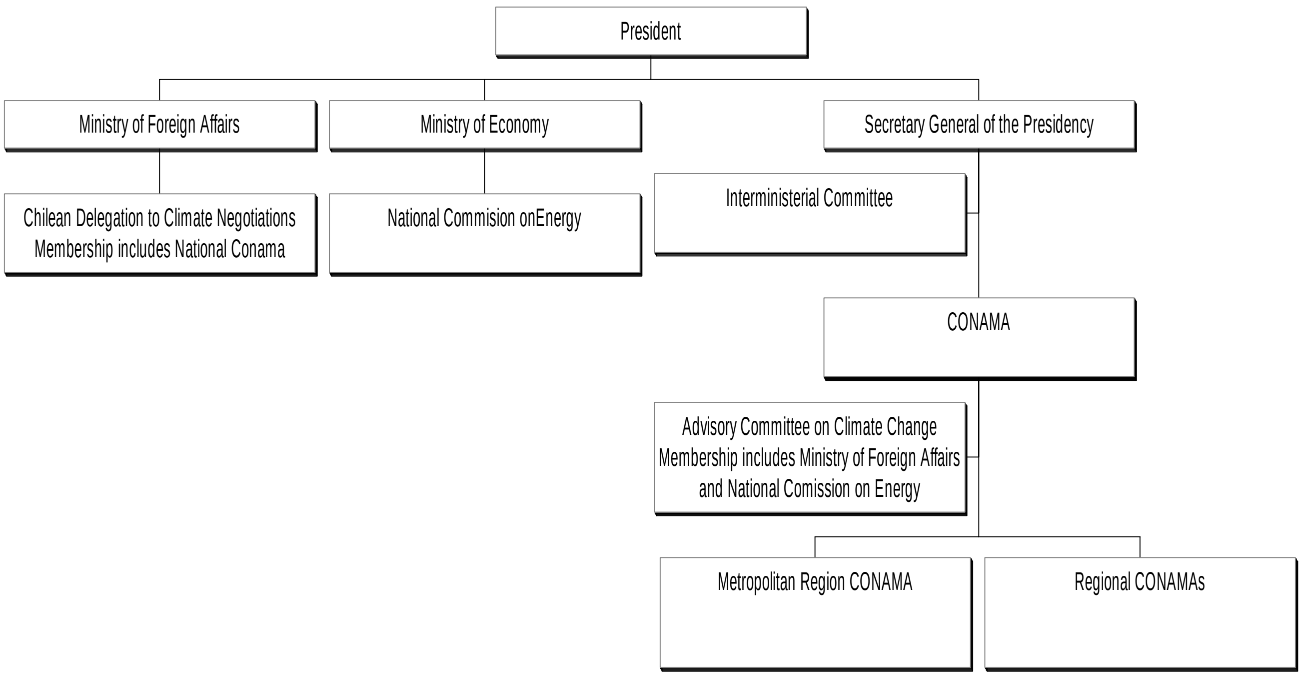


Policy Analysis

Involvement of Policy Makers : ICAP in the Chilean Policy-Making Context

The following diagram summarizes the institutional arrangements of the Chilean government agencies that are involved in environmental issues and implementation of mitigation measures.

Figure 7 Institutional Structure for Climate Policy and Implementation in Chile



The Minister of Foreign affairs is the policy-maker for the climate change negotiations. The National CONAMA is represented in the climate negotiations by Juan Pedro Searle. The National CONAMA's Advisory Committee on Climate Change includes representation by the Ministry of Foreign Affairs. National greenhouse gas mitigation goals would be adopted by the Ministry of Foreign Affairs, with input from the Advisory Committee on Climate Change and the Chilean negotiating team. It should be noted, however, that national policies declared at the highest levels and implemented throughout all government agencies are rare, especially in environmental policy. The technical review of these goals would occur through the National and Regional CONAMAs and Secretary of Energy. The National CONAMA sets local air quality mitigation goals, which the Regional CONAMAs implement.

On the GHG mitigation side, ICAP has built connections to the COP6 negotiating team and the CONAMA Advisory Committee through Mr. Juan Pedro Searle, who can draw on the ICAP results in his work in both of these groups. Members of these GHG policy-making groups have also been engaged through specific events, including a COP5 ICAP side-event and the Policy Makers' meeting in October 2000.

Among regional CONAMAs, which are the implementing agencies for air pollution mitigation measures, the Santiago Metropolitan Regional CONAMA is the most advanced in addressing environmental and energy policy issues. It frequently turns to the team of Mr. Luis Cifuentes for policy analysis, so he can use the ICAP project experience to inform discussions strategies for Santiago that incorporate both air quality and GHG mitigation. Thus strong connections have been established between ICAP and the important parts of the Chilean policy-making institutions. While the ultimate decision makers for national climate policies are not directly engaged, the ultimate decision-makers for local air quality mitigation goals can be engaged.

Implications for Policy Making: Applications and Limitations of Results

During October, 2000, ICAP results were presented and discussed in several contexts in Santiago, Chile, and these discussions reveal the applications and limitations of the ICAP program to date for policy-making. Based on participation in these events and discussions, there appear to be at least three important stakeholders: 1) a core of government technical employees, academic researchers, and representatives of non-governmental organizations who are familiar with climate change issues, who endorse the validity of the cobenefit principle and support the need for development of integrated strategies to address local environmental concerns and GHG mitigation. Within government, many of these people are key technical staff to the climate negotiators and Interagency Climate Change Committee; 2) representatives of business interests who are deeply concerned about economic impacts, and seek technical solutions, to meet local air quality goals; 3) local air quality decision makers who have very limited resources to address urgent air quality concerns, and who, as of now, date are not worried about GHG mitigation.

The first event was a Policy Makers' meeting consisting of a Seminar on Co-Benefits of Mitigating Air Pollution, and discussion in a Policy Makers' Round Table, on October 20, 2000, in which the results the analyses were presented, assessing the hypothesis that integrated strategies can address both GHG and local air pollution more effectively than strategies developed separately. Following the results presentation, Juan Pedro Searle moderated the round table discussion, the results of which are considered in the following sections. The round table participants represented key institutional stakeholders for the development of integrated policies, including the National Commission on Energy (CNE), the National Environmental Commission (CONAMA), the Foreign Ministry (RR. EE.), the Energy Research Program (PRIEN), and the United Nations Development Program (UNDP). Unfortunately, no representatives of the Metropolitan Region CONAMA attended the meeting.

During the round table, Juan Pedro Searle moderated a one-half hour discussion of the following questions:

- How can climate change and air pollution policies be harmonized?
- What is the usefulness of this information for policy makers, considering climate change objectives?
- How can decision-makers use this information to formulate energy policy?
- Is this type of information useful to make climate change issues more relevant in the opinion of the public and of politicians?
- Does this work help to increase recognition of the benefits that the CDM would have to attract investment in technologies that reduce local air pollution?

The analysis was thought to be helpful to decision makers in allowing consideration of complex factors in coordinating different goals. The participants observed that this kind of study can show where resources and policies should be directed and to avoid adopting measures that have lower cobenefits.

Directing international resources was raised as an important application of the results. For the consideration of international investors, the participants suggested that Chile may wish to develop a portfolio of projects that meet both goals. This could help organize input from multilateral and bilateral assistance projects and industry, and help target funds for climate change that could assist with local goals, such as the air Decontamination Plan of Santiago. Directing international resources to target such harmonized policies and measures would be particularly important if a Clean Development Mechanism were established.

In the development of harmonized policies, it was recommended that consideration should not be limited to air quality and GHGs, but that additional factors should be addressed, including: social issues, economic issues, quality of life, etc. Participants cited the need for increased interministerial cooperation, especially between the National Commission on Energy (dependent on the Minister of Economy) and the National Commission on the Environment. Presenting a challenge to the development of integrated strategies for local air pollution and GHG mitigation, the legal framework separates these policy issues. Also, meeting air quality goals may not be possible without using some measures that will increase GHG emissions.

The second event was the Clean Air Initiative Mini-Course. During this event, representatives of businesses cited the expense of meeting air quality objectives, and called for advanced technologies to assist in achieving these goals. Financial considerations are extremely important to this group, and GHG objectives would be of interest primarily if financial advantages could be gained. Also, some participants expressed their concern about a developing country worrying about global warming, which was considered the responsibility of developed nations.

The third policy relevant event was a discussion with Mr. Gianni Lopez, Director of the Metropolitan Region CONAMA. Given the pressure to meet the air quality goals, and the limited availability of funding to support mitigation measures, the Director is interested in studying the opportunities that may arise from considering the reduction in GHG vía the CDM for example.

Recommendations to Improve ICAP Results for Policy Making

Some conclusions can be obtained from the policy makers meeting and minicourse, both of which had active participation. A participant raised questions about targeting those measures that have positive benefits, in that some of them may occur without intervention. This suggests the need for a clearer understanding of the barriers to those measures. A more accurate understanding of costs and benefits of the mitigation measures would also help decision-makers in designing integrated strategies. While this is an old topic, which has been the center of a long-standing debate among engineers and economists, a refined understanding is crucial to this kind of analysis.

Another participant suggested that the analysis to date over-emphasizes Santiago, and that that emphasis influences policy outcomes. For example, residential wood burning in the south of Chile uses unsustainable fuel sources and causes local air pollution. Addressing this situation would require different policies from the Santiago situation. While data limitations were recognized, as energy data in the south is not disaggregated, data availability should not distort policy development, and it was suggested that nation-wide case studies could be conducted.

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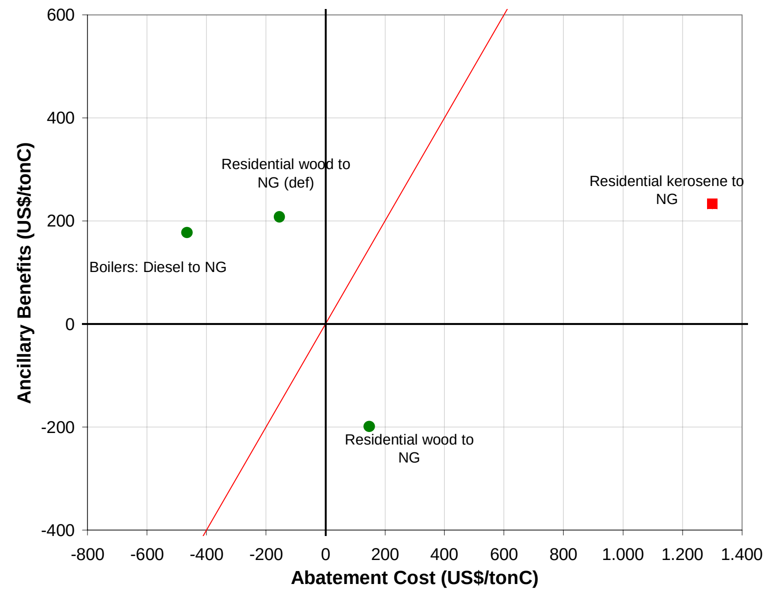
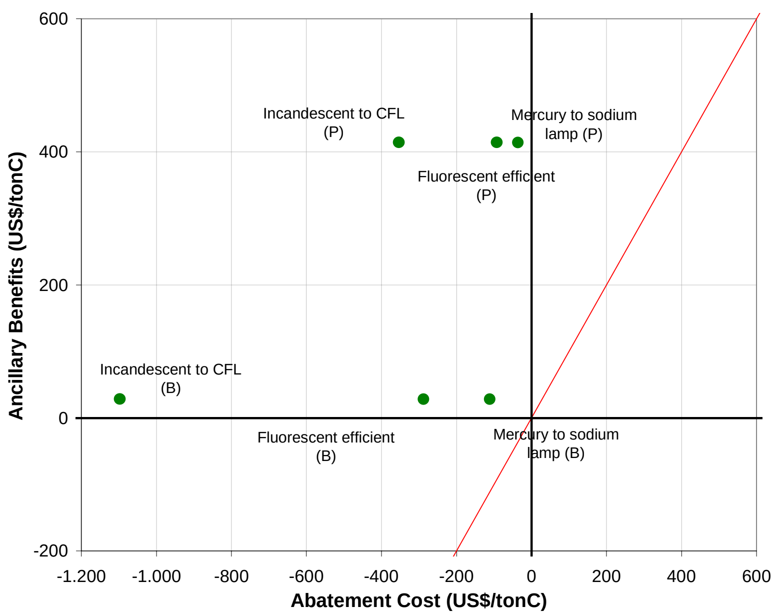
It was also recommended that further analysis could compare the Santiago Decontamination Plan with an integrated strategy, in terms of both expense and likely implementation speed.

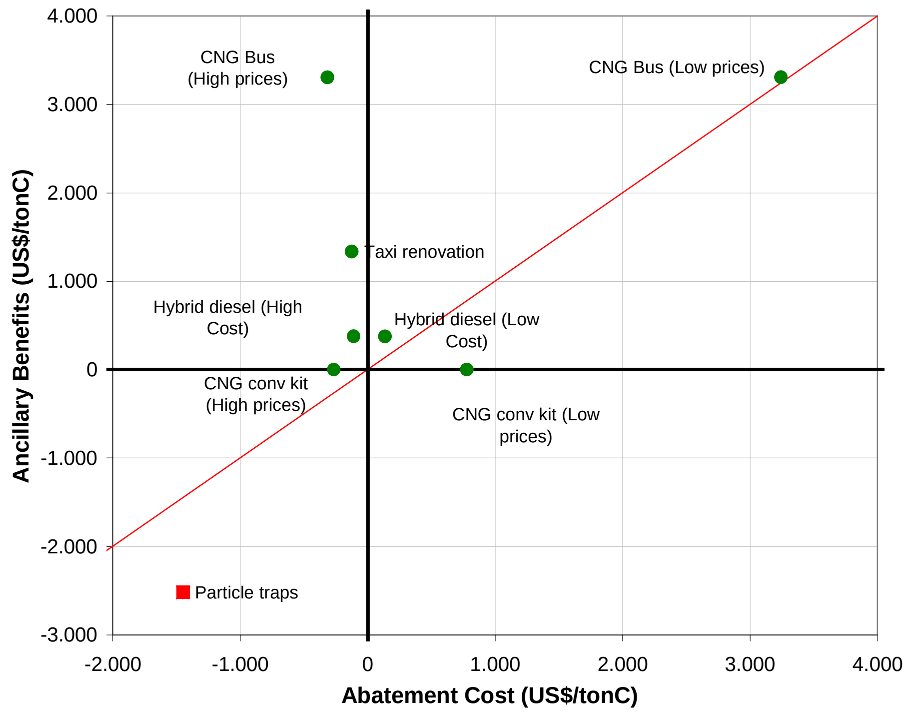
In terms of effecting decisions actually being made, there is a much greater possibility of real effects on policy makers in charge of the local pollution abatement plans, especially on Santiago's Decontamination Plan. These decisions are actually being taken now. By showing the potential benefits from an integrated strategy it is possible to affect the decision making process, in order to consider both the local and global implications.

Chile Appendix

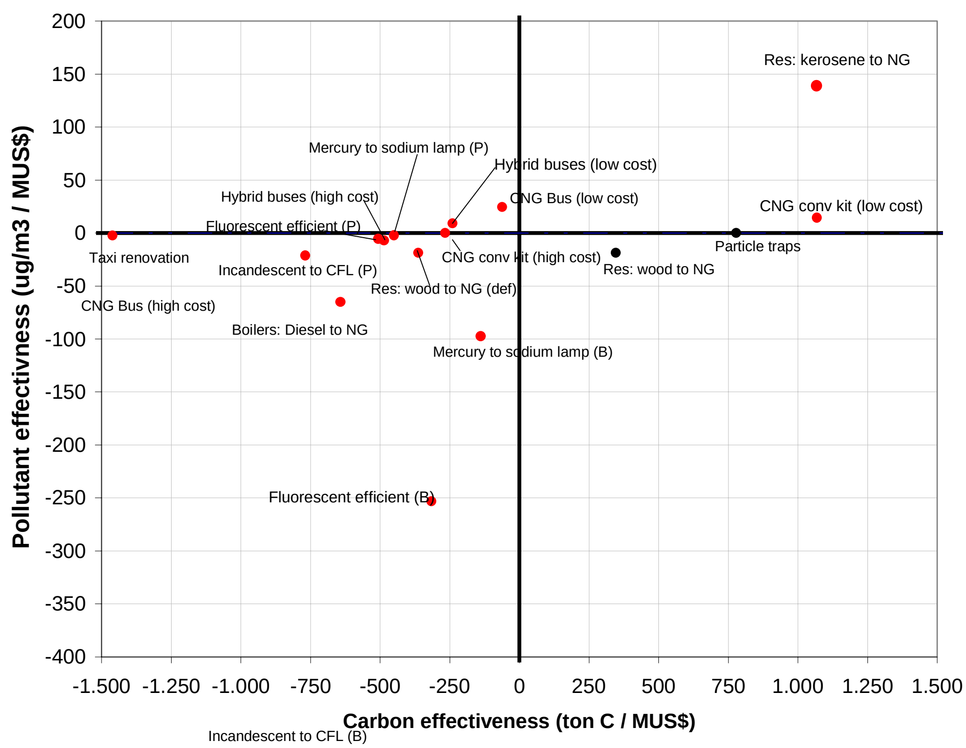
Mitigation Measures Detailed







4.000
3.000
2.000
1.000
0
-1.000
-2.000
-3.000
Ancillary Benefits (US$/tonC)
CNG Bus
(High prices)
CNG Bus (Low prices)
Taxi renovation
Hybrid diesel (High
Cost)
Hybrid diesel (Low
Cost)
CNG conv kit
(High prices)
CNG conv kit (Low
prices)
Particle traps
-2.000
-1.000
0
1.000
2.000
3.000
4.000
Abatement Cost (US$/tonC)



200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
Pollutant effectivness (ug/m3 / MUS$)
Res: kerosene to NG
Mercury to sodium lamp (P)
Hybrid buses (low cost)
Hybrid buses (high cost)
CNG Bus (low cost)
CNG conv kit (low cost)
Fluorescent efficient (P)
Particle traps
Taxi renovation
CNG conv kit (high cost)
Incandescent to CFL (P)
Res: wood to NG
Res: wood to NG (def)
CNG Bus (high cost)
Boilers: Diesel to NG
Mercury to sodium lamp (B)
Fluorescent efficient (B)
-1.500
-1.250
-1.000
-750
-500
-250
0
250
500
750
1.000
1.250
1.500
Carbon effectiveness (ton C / MUS$)
Incandescent to CFL (B)

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